NASA-CR-200627

Assessment of Leaf Area, Vine Vigor, and Grape Yield and Quality of Phylloxera-Infested and Non-Infested Grapevines in Napa County and Their Relationship to Leaf Reflectance, Chlorophyll, and Mineral Content

Final Report

NCC2-5062

March 8, 1996

by

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1. <u>Summary of Research</u>

<u>Background</u>

Grape Phylloxera will cause the California wine industry to lose over one billion dollars by the year 2000. Grape growers with grape phylloxera-infested soils graft scion varieties onto what are popularly termed "resistant rootstocks." Rootstocks, however, differ in their suppression of phylloxera: some do not support the insect at all, while other support low populations. In addition, phylloxera biotypes vary in their growth on different rootstocks. In California's Napa and Sonoma county vineyards, about 75% of the vines have AXR#1 rootstock that tolerates phylloxera biotype A. In the early 1980's biotype B emerged there. It so devastates AXR#1 that the vineyards must be replanted with rootstocks resistant to biotypes A and B. Timing replanting is difficult because vineyards do not decline uniformly. A patchwork of uninfested vines, infested but asymptomatic vines, declining but productive vines, and unproductive vines typifies most vineyards. The grower must determine the proportion of vines in each category and estimate the yield loss the stressed vines will suffer.

During 1993, 1994 and 1995 the NASA-Ames GRAPES study used remotely sensed leaf reflectance, temperature, and canopy size data and geographic information system (GIS) technology to study infestations in Napa County vineyards. As part of this study a vineyard with a range of phylloxera induced stress and accompanying symptoms -- reduced growth, less chlorophyll, and lower reflectance of near infrared:red light -- was investigated to determine the degree to which stress measurements predict the current and following season's yields from stressed vines relative to healthy vines. Such yield estimates could enable a grower -- before obtaining actual yields -- to calculate the economics of replanting. A grower who decided to replant would have 2-14 months additional lead time to plan and prepare.

Objectives

California State University, Chico, was responsible for the following parts of this project (1) collaborated on experimental design and selection of field sites, (2) measured vine leaf area of infested and non-infested vines, (3) evaluated the impact of Phylloxera infestation on vine vigor and grape yield, (4) helped with the evaluation of test plots for the presence of other pests and diseases, and (5) shared in data analysis and authorship of journal articles. When the G.R.A.P.E.S. project was originally designed in 1993 (JRI NCA2-815), it was thought that we would also be responsible for investigating vineyard diseases such as powdery mildew, viruses, and crown gall that might confound the reflectance signatures of phylloxera-infested vines. A survey of the research site in the late summer of 1993 revealed the presence of so little disease -- one vine appeared to have Eutypa -- that this objective was not pursued further.

Materials and Methods

A detailed description of the overall approach of the G.R.A.P.E.S. Project can be found in "Leaf Reflectance Patterns Relating to Phylloxera Infestations for G.R.A.P.E.S. (Grapevine Remote Sensing Analysis of Phylloxera Early Stress)" by John A. De Benedictis et. al., the final report for NCC2-5046. A description of the investigative approach for the research relating phylloxera infestation to leaf color, vine size, and grape yields in can be found in the manuscript "Relating Leaf Color and Vine Size to Yields in a Phylloxera Infested Vineyard" which is attached to this report. Methods used to study the differences between the effects of acute and chronic stress on leaf reflectance can be found in the attach draft manuscript "Yield and Chlorophyll Changes in Chronically and Acutely Stressed Grapevines -- Implications for Remote Sensing to Anticipate Yield Ranks of Vineyard Plots."

Results

Leaf Color, Vine Size, Yields and Phylloxera Infestation

During 1995 the manuscript "Relating Leaf Color and Vine Size to Yields in a Phylloxera Infested Vineyard," which reports the relationship between measures of vine stress and future yields studied during the 1993 and 1994 growing seasons, was revised by members of the G.R.A.P.E.S. team. This manuscript was submitted to Vitis in January, 1996, and a copy is attached to this report. No yield data were collected in 1995.

Yield, Chlorophyll and Chronic vs. Acute Stress

In 1995 a manuscript "Yield and Chlorophyll Changes in Chronically and Acutely Stressed Grapevines -- Implications for Remote Sensing to Anticipate Yield Ranks of Vineyard Plots" was also drafted and is in circulation to the NASA, Mondavi, and University of California authors for feedback. It is also attached to this report.

Leaf Calcium, Magnesium, and Potassium and Phylloxera Infestation

Many phylloxera-infested vines exhibit leaf symptoms that resemble the reactions to potassium deficiency -- yellowing and marginal leaf burn. However, the G.R.A.P.E.S. project has found that leaf potassium levels have not correlated with the extent of phylloxera-infestation. The literature on leaf symptoms notes that symptoms associated with potassium deficiency are often the result of potassium:calcium or potassium:magnesium imbalance[7]

In 1995 leaves were collected and analyzed for calcium and magnesium as well as potassium and nitrogen content according the methodology described in De Benedictis et. al. Averages of weight percent of potassium, calcium, and magnesium in May and July (see Tables 5, 6, and 7 of De Benedictis et. al.) were analyzed for their relation to phylloxera infestation levels in May and July (Table 1 De Benedictis et. al.). The results of these analyses (see attached figures) show that there is no correlation between any of the three ratios investigated -- potassium to magnesium, magnesium to calcium, and calcium plus magnesium to potassium -- and the averages of phylloxera infestation ratings for the research plots 1-9 and 12 in the Q2 vineyard study site.

Grape Quality and Phylloxera Infestation

Grape quality for wine making was assessed in 1994 by the Robert Mondavi Winery's experimental wine cellar. Spectral vines from each plot were harvested and their fruit pooled, crushed, and a one gallon sample was inoculated following the routine procedures for small lot fermentations.

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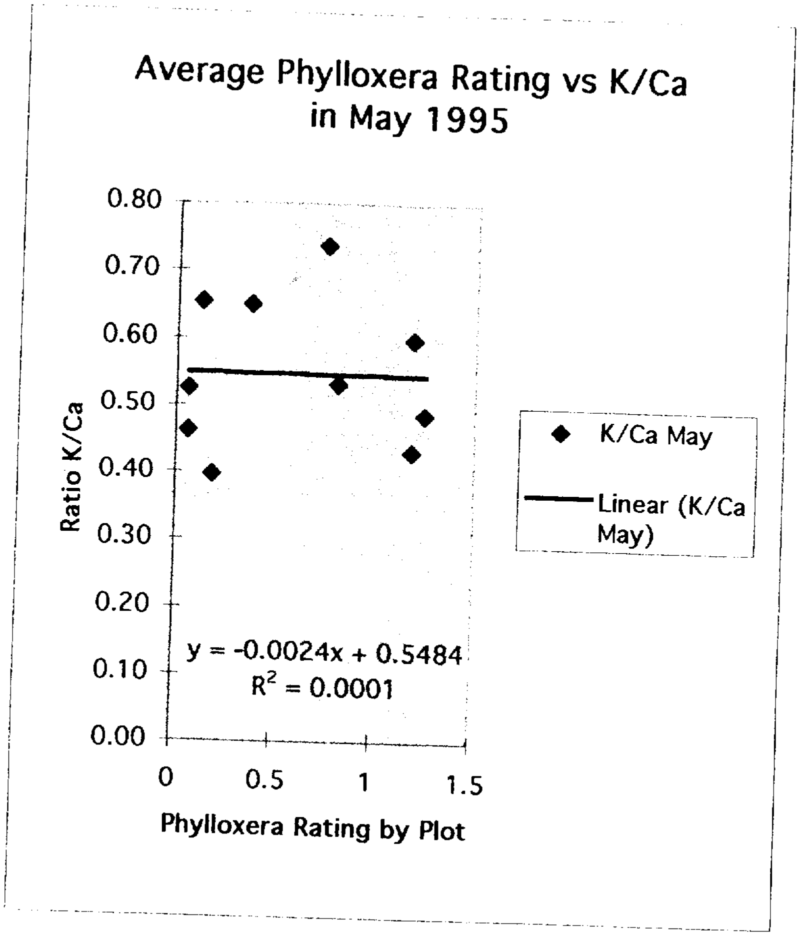
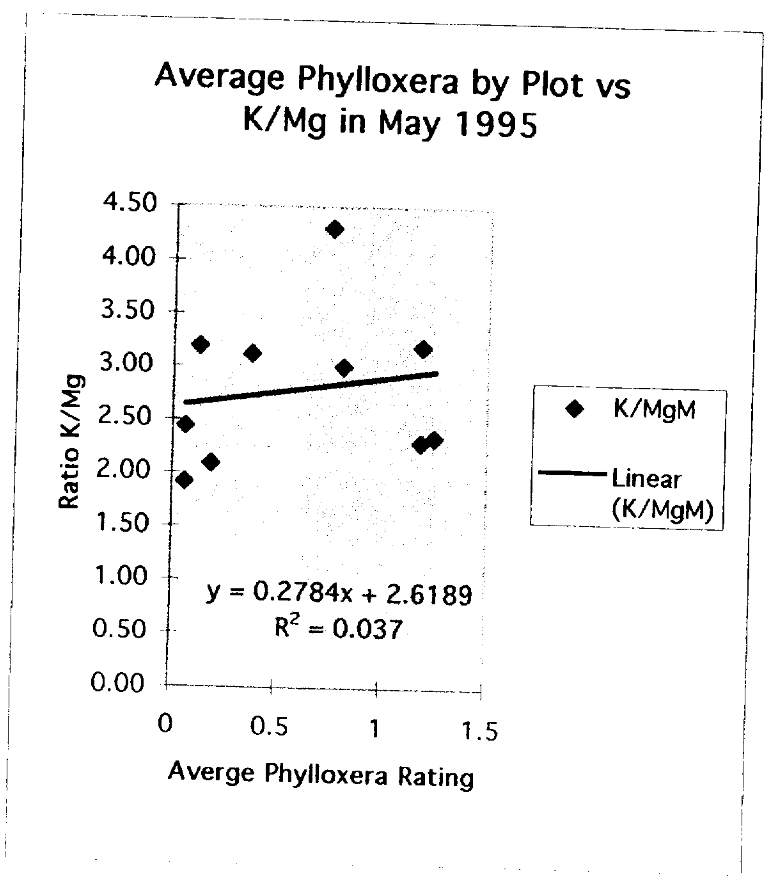
[7] Fregoni, M., *Exigences d'éléments nutritifs en viticulture*. Bulletin de L'O.I.V., 1985. **650-651**: p. 416-434 and Levy, J.F., *Identification et etude par l'analyse foliare de quelques carences alementaires de la vigne*. Vignes et Vins, 1965. **138**: p. 18-24.

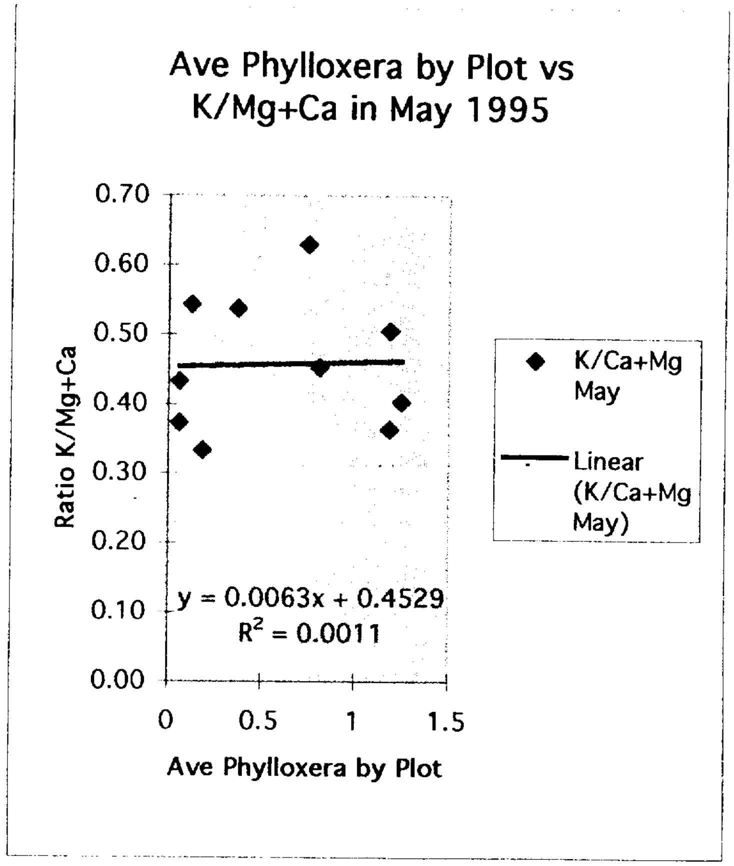
Fermentation rates were determined and found to be the same for all plots irrespective of their phylloxera-infestation status.

2. Final Report of Inventions and Subcontracts

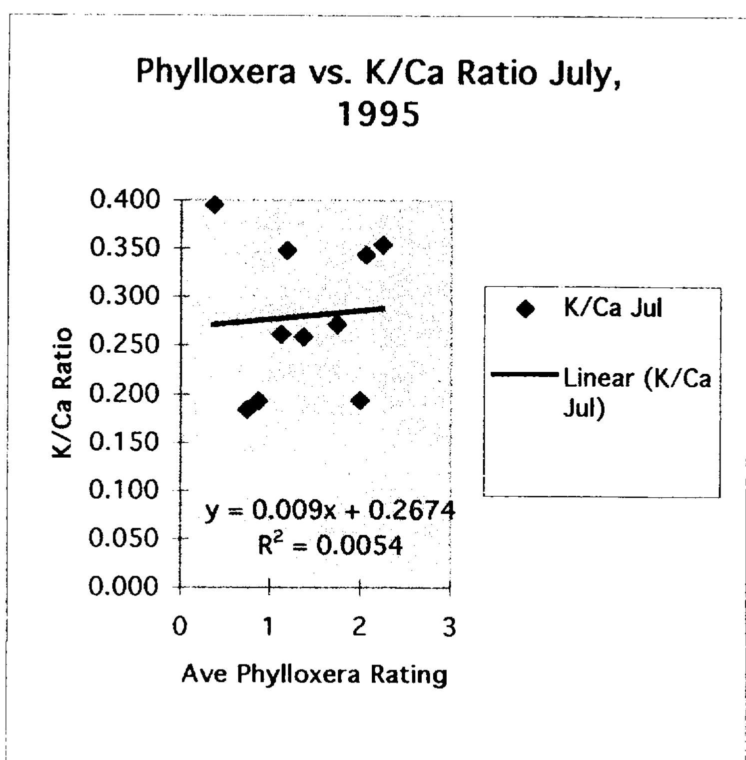
There were no inventions made during the award period. No subcontractors were used for this project.


Average Phylloxera Rating vs K/Ca in May 1995
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Ratio K/Ca
0
0.5
1
1.5
Phylloxera Rating by Plot
y = -0.0024x + 0.5484
R² = 0.0001
K/Ca May
Linear (K/Ca May)

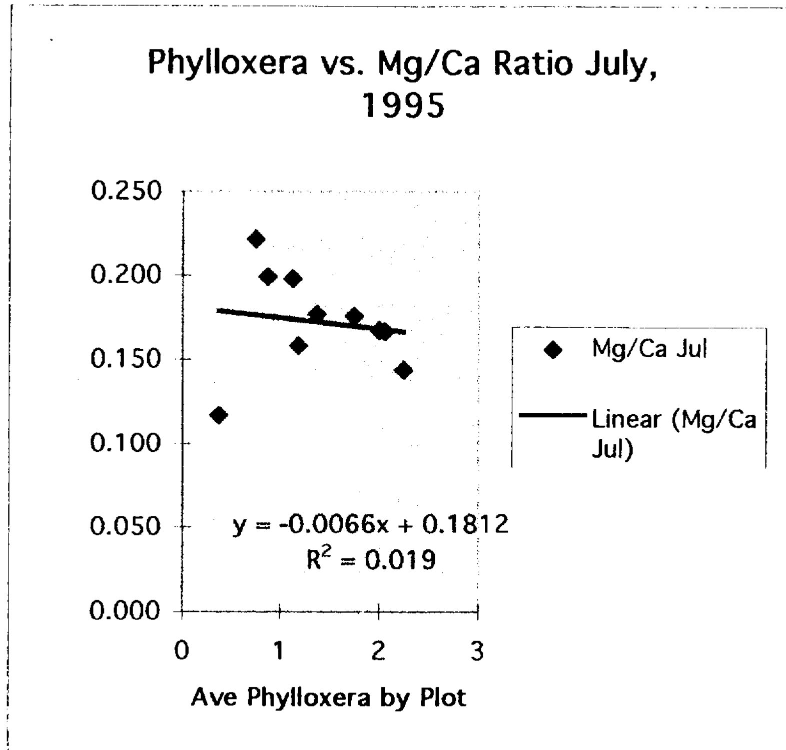

Average Phylloxera by Plot vs K/Mg in May 1995
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Ratio K/Mg
0
0.5
1
1.5
Averge Phylloxera Rating
y = 0.2784x + 2.6189
R² = 0.037
K/MgM
Linear (K/MgM)

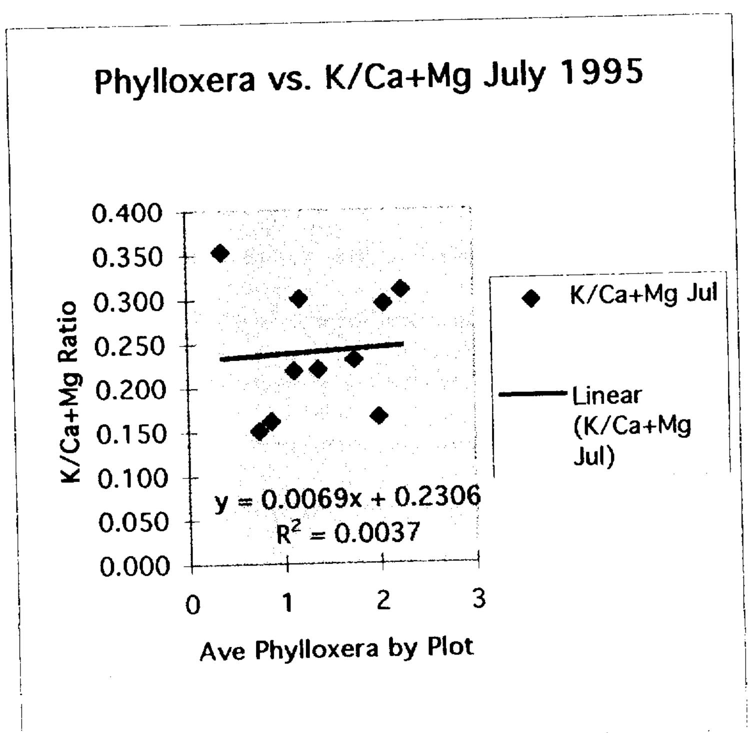


Ave Phylloxera by Plot vs K/Mg+Ca in May 1995
Ratio K/Mg+Ca
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
0.5
1
1.5
Ave Phylloxera by Plot
y = 0.0063x + 0.4529
R^2 = 0.0011
K/Ca+Mg May
Linear (K/Ca+Mg May)



Phylloxera vs. K/Ca Ratio July, 1995
K/Ca Ratio
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0
1
2
3
Ave Phylloxera Rating
y = 0.009x + 0.2674
R^2 = 0.0054
K/Ca Jul
Linear (K/Ca Jul)


Phylloxera vs. Mg/Ca Ratio July, 1995
0.250
0.200
0.150
0.100
0.050
0.000
0
1
2
3
Ave Phylloxera by Plot
y = -0.0066x + 0.1812
R² = 0.019
Mg/Ca Jul
Linear (Mg/Ca Jul)


Phylloxera vs. K/Ca+Mg July 1995
K/Ca+Mg Ratio
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0
1
2
3
Ave Phylloxera by Plot
y = 0.0069x + 0.2306
R² = 0.0037
K/Ca+Mg Jul
Linear (K/Ca+Mg Jul)

RELATING LEAF COLOR AND VINE SIZE TO YIELDS IN A PHYLLOXERA INFESTED VINEYARD

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ABSTRACT: Phylloxera infestation and associated vine symptoms usually spread unevenly across a vineyard. This uneven spread complicates yield estimates and vineyard replacement decisions. In a Cabernet Sauvignon vineyard with AXR#1 rootstocks the current season's and following season's yields of 40-vine plots correlated ($r \geq 0.77$, $p \leq 0.05$) with early to midseason leaf and canopy spectra measured in the field, laboratory and remotely with aircraft-borne sensors.

INTRODUCTION

Grape *(Vitis vinifera* L.) growers with grape phylloxera (*Daktulosphaira vitifoliae* (Fitch)) infested soils graft scion varieties onto "resistant rootstocks." Rootstocks, however, differ in their suppression of phylloxera. Some support almost no insects, while others support low, non-damaging populations. Also, phylloxera biotypes vary in their growth on different rootstocks (Granett, Goheen et al. 1987) (DeBenedictis and Granett 1993). In California's Napa and Sonoma County vineyards, about 70% of the vines were grafted to AXR#1 rootstock which tolerates phylloxera biotype A. In the early 1980's biotype B emerged there. It so devastates AXR#1 that the vineyards must be replanted with rootstocks resistant to biotypes A and B.

Timing of replanting is difficult because vineyards do not decline uniformly. A patchwork of uninfested vines and infested asymptomatic vines, vines with declining productivity, and unproductive vines typifies most infested vineyards. Our goal was to determine if the ranking of such an array of vines by stress indicators would correspond to their future ranking by yield and thereby improve the calculation of the economics and timing of replanting. Knowing months in

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advance that a vineyard warrants replanting enables growers to utilize the lead time to purchase replacement rootstocks and scions, acquire trellis, irrigation, and other materials, arrange financing, and advise wineries of reduced grape supply.

Because, phylloxera-infested vines on susceptible rootstocks eventually become chlorotic with lower yields and leaf area, we reasoned that vine leaf area and leaf chlorophyll would correlate with yield. Chlorophyll shares the attributes ascribed to nitrogen as a "physiological indicator of cumulative stress:" it does not fluctuate daily, but it does respond to long-term stress; moreover, it is easy to measure (Stutte and Stutte 1992) .

MATERIALS AND METHODS

The Vineyard

We followed the progress of the phylloxera infestation and resulting decline in a Cabernet Sauvignon vineyard block near Oakville, California from 1993-94. The vines were grafted to AXR#1 rootstock and, according to the vineyard manager, had been infested with grape phylloxera since 1992. The vines were planted in 1981 on Clear Lake clay and Bale clay loam. The vineyard is nearly level, covers 12.2 acres, is drip irrigated, and has its 3.65m wide rows oriented NE to SW. Vines are 2.43m apart in rows. The vine trunks divide at 1.1m (the height of the first trellis wire) to form arms that extend in each direction down the vine row. A second wire 0.4m above the first supports fruiting canes.

The vineyard managers employed the same commercial practices for vines in and outside the plots. Tilling removed under-vine and between row vegetation to avoid confounding grape leaves with other vegetation when aircraft mounted scanners recorded vineyard reflectance. Summer pruning equalized mean shoot and cluster numbers among plots in 1993, but not in 1994.

Plot Selection

We used 1992 infrared aerial photographs in conjunction with May 7, 1993, phylloxera sampling to select nine 40-vine plots. Plots 1, 2, and 3 exhibited reduced growth symptomatic of phylloxera infestation in the photographs; the other six plots appeared to be healthy. Figure 1 indicates the location and identifying number of each plot and the number of phylloxera-infested vines (out of 18 sampled) by July, 1993.

As shown in Figure 1, the phylloxera infestation was greatest in the southwest portion of the block and decreased from south to north except for second heavy infestation in plot 6. Consequently, we had to select plots with the desired infestation and decline characteristics along this gradient, so we couldn't randomize "treatments" to eliminate effects due to soil differences, drainage, or other undetected geographic factors that might have existed along the same gradient.

Fourteen vines per plot were sampled only to estimate leaf area. The remaining 26 vines per plot were sampled for yields, pruning weights and chlorophyll.

Phylloxera Sampling

Figure 2 illustrates the layout of our 40 vine plots. We selected 8 vines ("primary vines", labeled "P") in the middle two rows to represent the plot for phylloxera estimates and research objectives to be reported elsewhere. To avoid damaging the roots of the primary vines (which might affect other research objectives), we sampled 9 vines (labeled "S1" or "S2" in Figure 1) along diagonals adjacent to the primary vines alternating between S1 and S2 each sampling date. Each primary vine was given the average phylloxera rating of the two neighboring sampled vines.

We rated the vines on a 0 to 4 scale as follows: 0 = no phylloxera; 1 = just crawlers, or nodosities, or only 1-5 adults per 15 cm of root; 2 = 5 to 10 phylloxera per 15 cm of root; 3 = 10 to 25 feeding sites; 4 = roots densely covered with phylloxera. A vine was assigned the rating of the 15 cm piece with the highest infestation level. We used the averages of the June 10 and July 22 ratings as the estimated phylloxera level in 1993 and the higher of the May 25 or July 26 ratings for 1994 estimates.

Fruit Yield and Pruning Weights

On September 27, 1993, we recorded the cluster number and weight of mature fruit for all vines except the 14 per plot used to estimate leaf area. On September 27, 1994, we took yield data from the 8 primary vines per plot. In 1993 we collected pruning weights after leaf fall from the primary vines.

Leaf Area Measurements

We estimated average leaf area by shoot sampling 14 vines per plot -- seven on July 15 and 22, and seven on August 17, 18, and 19, 1993. We recorded the number of shoots and then removed two randomly selected shoots per vine. We put the sampled shoots in translucent plastic bags and transferred them to a shaded site where we removed leaves with widths greater than 1.5 cm and placed them in Ziploc® freezer bags or paper envelopes and stored them in insulated, chilled boxes. We measured leaf area with a LI-COR LI 3100 area meter (LiCor, Inc., Lincoln, NB) and recorded main leaf area and lateral leaf area. The leaf area per shoot times the number of shoots per vine yielded an estimate of the leaf area per vine. We used this value to estimate the total leaf area per plot.

Field Chlorophyll Measurements

The Minolta SPAD-502 chlorophyll meter (Minolta Corp., Ramsey, N.J.) converts leaf transmittance of 940 and 650 nm light to SPAD units, which had the following relationship to grape leaf chlorophyll concentration: Chlorophyll (mg/cm^2) = 0.001605*SPAD - 0.009951. $R^2 = 0.914$.

We averaged six SPAD readings per leaf. In 1993 measured leaves were two nodes above the second cluster on vigorous shoots. All sampled shoots had clusters, generally two, but occasionally three. In the latter case, the sampled leaf opposed a cluster. After establishing that the coefficient of variation among selected shoots was less than 10%, we took one leaf from one vigorous shoot per vine and did not distinguish between shoots that grew from canes or spurs. We chose shoots on the southeast side. We took chlorophyll meter readings May 18, June 9, July 15, August 19, September 3 and 16, and October 20.

In 1994 we averaged the readings of 4 leaves per vine, two from each side. (There were no differences between the southeast and the northwest sides.) We took leaves opposite the second cluster on May 5, and the second leaf above the second cluster on May 25, June 29, and July 26.

Laboratory Reflectance Measurements

We collected a leaf from each primary vine and placed it in a Ziploc® bag before storing it in a chilled cooler chest for transport to the laboratory where we measured its reflectance within 12 hours. SPAD readings did not change during the 12 hour maximum storage period, which indicated stable chlorophyll concentrations. Over the visible and near-infrared region (here 400-2500 nm) NIRSystems Model 6500 spectrophotometer (Silver Spring, MD) measured reflectance at every 2 nm. Of particular interest was the reflectance amplitude at the green peak (GP) at 550 nm and the red edge inflection point (REIP) in the 680-750 nm region, found in previous studies (Vogelmann, Rock et al. 1993) (Carter and Miller 1994) to be sensitive to plant stress. Measurement dates in 1993 were the same as for the chlorophyll meter readings described above, except for the addition of a July 26 and the omission of the September 16 measurements.

Canopy Reflectance Measurements

Digital imagery was collected over the vineyard by an airborne CASI instrument (ITRES Research, Alberta, Canada) on July, 28, 1993. CASI measured at-sensor radiance (solar radiance reflected from the surface and atmosphere) at 787 and 680 nm. The spatial resolution of the data was about 1.8 m x 1.8 m. On August 1, 1994, the Electro-Optic Camera (NASA's Ames Research Center, Moffett Field, CA) measured at-sensor radiance at 775 and 680 nm. The spacial resolution of the data was about 4.6 m x 4.6 m. (Johnson, Lobitz et al. 1995) From these data we computed near infrared to red reflectance, NIR:RED; 787 or 775 : 680 nm is related to canopy leaf area. (Bauer 1985) (Tucker 1979) .

Visual Scoring

On September 23, 1993 and on July 26, 1994, two of us scored vines for chlorosis by assigning a value of 1 to severely chlorotic vines, 2 to moderately chlorotic vines, 3 to slightly chlorotic, and 4 to nonchlorotic vines. In 1994 we used analogous categories to score vines for size and for marginal discoloration/scorching. (We scored vines for marginal discoloration/scorching, because preliminary observations indicated that this symptom was common on phylloxera-infested vines and would, therefore, correlate with yields.)

Statistical Analysis

We analyzed data using SYSTAT software (SYSTAT 1992).

RESULTS

A regression of 1993 yields per plot against 1993 mean phylloxera ratings produced a coefficient of determination, (R^2), of 0.85 -- a result in accord with our initial observations that phylloxera was the principal stress factor affecting yield. For the regression of these 1993 mid-season phylloxera ratings against 1994 yields (see Figure 3) the R^2 was 0.92, which suggested that early to mid-season field, laboratory, and remotely sensed measurements might also correlate with the following season's yields as well as current season's. We separated 1993 data into those collected between May 18 and September 3, and those collected later which would not help growers anticipate current season's yields. (Correlations among late season, 1993 measurements and between them and 1993 and 1994 yields are in Table 1, which also contains correlations with leaf area -- a destructive measure too time consuming to be of practical use.)

Early to midseason 1993 measurements of NIR:RED and SPAD correlate highly with 1993 and 1994 yields (see Table 2). As Table 1 indicates, GP and REIP closely correlate with SPAD and for brevity are omitted from Table 2 and the following results of regressing spectral measurements against yields.

Regressions of May - September 1993 SPAD against mean plot yields for 1993 and 1994 are significant ($p \leq 0.05$) and displayed in Figure 4. The regressions of 1993 NIR:RED against mean plot yields of 1993 and 1994 are significant ($p \leq 0.001$). NIR:RED's close correlation with each of the May - September SPAD values suggests a May - September NIR:RED series regressed against yields would closely match Figure 4. The regression of 1994 NIR:RED versus 1994 yield is significant ($p \leq 0.001$).

Regressions of May 25, June 29, and July 26 1994 SPAD versus 1994 yield (not shown) do not significantly differ from those of 1993 SPAD vs. 1994 yields. In short, plotting the following season yields against current season SPAD readings, gives nearly the same regressions as obtained with SPAD readings taken 12-16 months later.

In Figure 4 slopes within regression line sets -- 1993 SPAD versus 1993 yields and 1993 SPAD versus 1994 yields -- do not significantly differ. However, three of the five pairs of lines that regress the same SPAD values against different years' yields have different slopes ($p \leq 0.05$).

Table 3 contains correlations among 1994 yields, phylloxera ratings, NIR:RED, and May - July SPAD readings, and July vine chlorosis and size scores.

DISCUSSION

The significant regressions between yield and several preharvest, quantifiable measurements offer growers the possibility of anticipating by 5-16 months yield differences among vineyard plots. These will be rank differences among plots rather than absolute differences, because the regression coefficients (slopes) may vary from year to year as Figure 4 shows. In Figure 4 slopes of the 1993 regression lines would have been greater (more like those of 1994) if cluster numbers per vines had not been equalized in 1993.

Of the methods we used, aircraft mounted sensors to record NIR:RED and the chlorophyll meter are the most practical for quantifying differences within vineyards. A remote sensing service can scan quickly several thousand acres, process the data and present growers with NIR:RED in the form of digitized images. Moreover, data from two flights can be processed to produce images that reveal changes that occurred between flights. However, the use of NIR:RED is limited to clean cultivated vineyards. Also, overflight costs will place remote sensing out of the reach of growers who cannot share the costs or amortize them over many acres.

The chlorophyll meter is an affordable alternative for growers without access to a remote sensing provider and for growers whose vineyard or financial conditions rule out remote sensing. Whereas a remote sensor with adequate resolution can measure each vine in a vineyard, growers with chlorophyll meters will probably choose to measure a sample of vines, because each leaf will require at least one minute to select, measure, record the SPAD value, and move to the next vine.

The chlorophyll meter offers advantages over other ground level methods of accessing vines: 1) whereas the chlorophyll meter is a grower-affordable field instrument, a NIRS spectrophotometer is an expensive laboratory instrument, 2) SPAD readings are largely independent of meter operator and can be compared to readings taken months or a year later -- data qualities that are difficult to obtain with subjective vine scoring, 3) taking chlorophyll readings is noninvasive, in contrast to labor-intensive phylloxera sampling which may open sites for invasion by pathogens.

CONCLUSION

Early symptoms of phylloxera infestation include reductions in chlorophyll and vine size that correlate with reductions of current and following season yields. Leaf and canopy spectral properties can delineate stressed areas in a vineyard and can rank these areas by yield 5 to 16 months before harvest.

ACKNOWLEDGEMENTS

We thank Roy Armstrong, Cindy Bell, Ashley Derr, Chris Hlavka, Jennifer Mathews, Kathy Neal, Joan Salute, and Lori Smith, for their assistance in collecting data. Funding was provided by NASA grants NCC2-5046, NCA2-815, and NCCA-5062. Robert Mondavi Winery provided vineyard access and data, field assistance, and the support of vineyard managers and researchers Daniel Bosch, Ben Henry, and Andy Bledsoe.

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Tables

	Yield 1993	Yield 1994	SPAD Sep 16	SPAD Oct 20	REIP Sep 16	REIP Oct 20	GP Sep 16	GP Oct 20	Pruning Weight	Leaf Area
SPAD Sep 16	0.89	0.89								
SPAD Oct 20	0.95	0.97	0.89							
REIP Sep 16	0.91	0.89	0.99	0.90						
REIP Oct 20	0.92	0.98	0.84	0.97	0.83					
GP Sep 16	-0.91	-0.84	-0.98	-0.90	-0.97	-0.81				
GP Oct 20	-0.95	-0.91	-0.89	-0.97	-0.90	-0.92	0.93			
Pruning wt.	0.73	0.77	0.87	0.81	0.86	0.74	-0.86	-0.85		
Leaf Area	0.76	0.57	0.56	0.65	0.59	0.66	-0.65	-0.77	0.60	
Chlorosis	-0.93	-0.93	-0.84	-0.96	-0.84	-0.96	0.85	0.95	-0.75	-0.76

Table 1.

	Yield 1993	Yield 1994	Phyll-oxera	NIR: RED	SPAD May 18	SPAD Jun 9	SPAD Jul 15	SPAD Aug 19
Phylloxera	-0.94	-0.96						
NIR:RED	0.93	0.90	-0.98					
SPAD May 18	0.83	0.85	-0.92	0.94				
SPAD Jun 9	0.92	0.80	-0.87	0.92	0.85			
SPAD Jul 15	0.85	0.85	-0.94	0.96	0.93	0.88		
SPAD Aug 19	0.83	0.77	-0.89	0.94	0.94	0.87	0.96	
SPAD Sep 3	0.96	0.92	-0.95	0.96	0.91	0.96	0.92	0.90

Table 2.

	Yield	Phyll-oxera	NIR: RED	SPAD May 5	SPAD May 25	SPAD Jun 29	SPAD Jul 26	Chlor-osis	Size
Phylloxera	-0.70								
NIR:RED	0.92	-0.80							
SPAD May 5	0.95	-0.72	0.89						
SPAD May 25	0.95	-0.79	0.94	0.86					
SPAD Jun 29	0.96	-0.67	0.91	0.85	0.97				
SPAD Jul 26	0.99	-0.78	0.93	0.94	0.96	0.96			
Chlorosis	-0.80	0.73	-0.73	-0.90	-0.73	-0.63	-0.81		
Size	-0.99	0.76	-0.92	-0.97	-0.93	-0.93	-0.99	0.84	
Leaf burn	-0.28	0.29	-0.26	-0.01	-0.46	-0.47	-0.31	-0.10	0.18

Table 3.

Table Captions

Table 1. Pearson linear correlation coefficients among 1993 and 1994 yields, leaf area per vine and late season, 1993 vineyard measurements.

Table 2. Pearson linear correlation coefficients among 1993 and 1994 yields and May 18 - September 1993 vineyard measurements.

Table 3. Pearson linear correlation coefficients among 1994 yields and 1994 vineyard measurements.

Figure Captions

Figure 1 Map of study plots. Numbers before dashes give plot number designation. Numbers after dashes equal the number of vines per plot (of 18 sampled) with detected phylloxera by July 1993. For example, 2-18 is plot 2, with 18 vines with phylloxera of 18 sampled vines.

Figure 2. Layout of a 40 vine plot layout showing primary vines (P), vines sampled for leaf area (L), vines sampled for phylloxera (S1) and (S2).

Figure 3. Regressions of mean 1993 phylloxera scores versus mean vine yields for 1993 and 1994. Numbers next to data points identify plots.

Figure 4. Regressions of mean SPAD values in 1993 versus mean vine yields for 1993 and 1994. Numbers on regression lines indicate sampling dates.

Figures

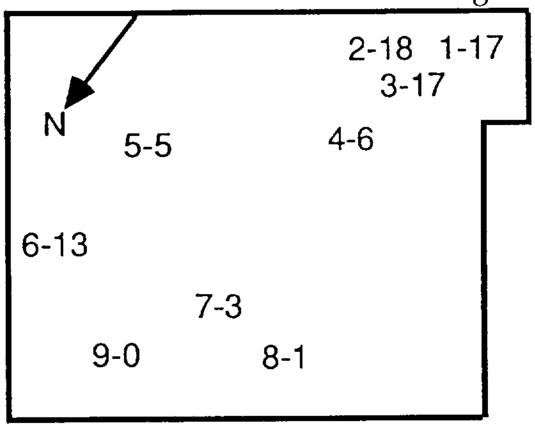

Figure 1

L	L	S1	L
L	S2	P	S1
S1	P	S2	L
L	S1	P	S2
S2	P	S1	L
L	S2	P	S1
S1	P	S2	L
L	S1	P	S2
S2	P	S1	L
L	S2	L	L

Figure 2

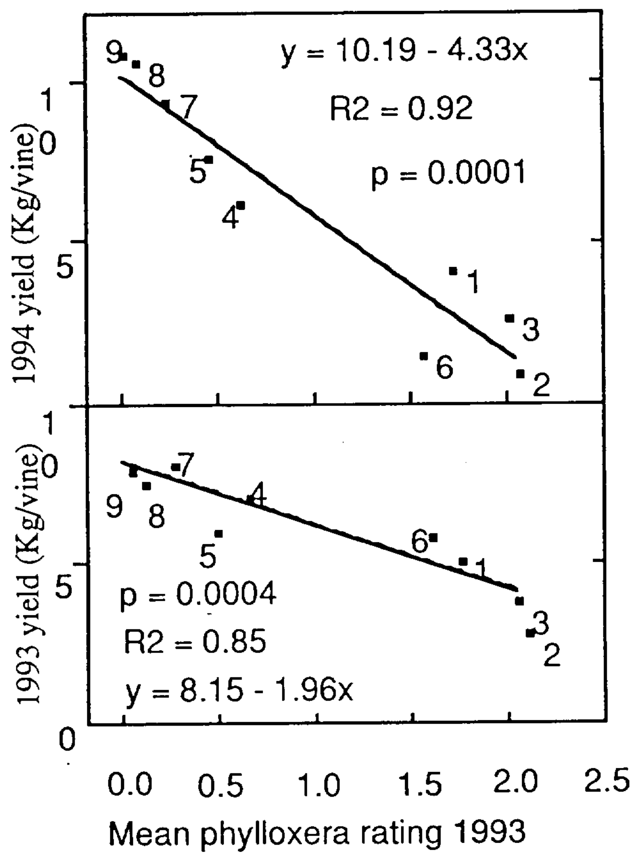
y = 10.19 - 4.33x
R2 = 0.92
p = 0.0001
1994 yield (Kg/vine)
1993 yield (Kg/vine)
p = 0.0004
R2 = 0.85
y = 8.15 - 1.96x
0.0 0.5 1.0 1.5 2.0 2.5
Mean phylloxera rating 1993

Figure 3

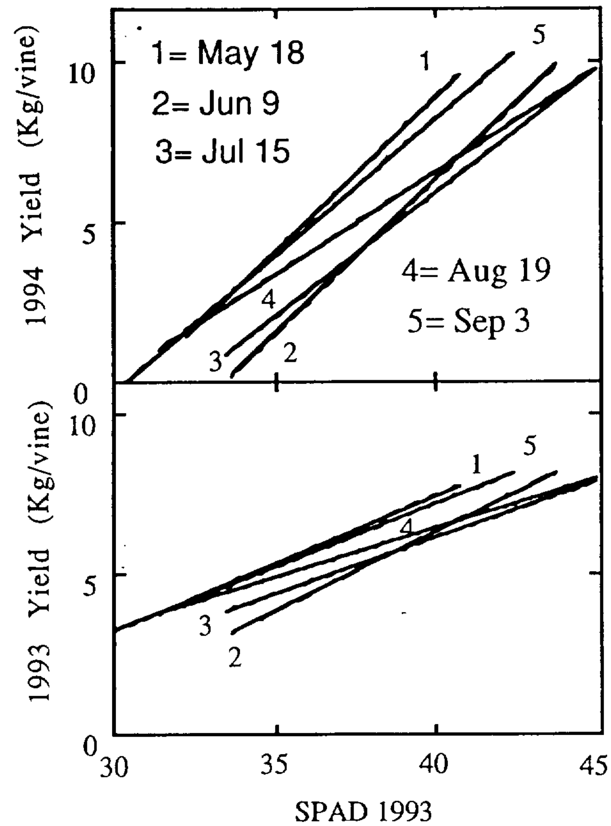
1= May 18
2= Jun 9
3= Jul 15
4= Aug 19
5= Sep 3
1994 Yield (Kg/vine)
1993 Yield (Kg/vine)
0
5
10
30
35
40
45
SPAD 1993
1
2
3
4
5

Figure 4

YIELD AND CHLOROPHYLL CHANGES IN CHRONICALLY AND ACUTELY STRESSED GRAPEVINES -- IMPLICATIONS FOR REMOTE SENSING TO ANTICIPATE YIELD RANKS OF VINEYARD PLOTS

ABSTRACT

Phylloxera stressed vines suffer reduced yields and lower concentrations of leaf chlorophyll. Root-pruned vines suffer reduced yields and for a time reduced chlorophyll, but then chlorophyll concentrations recover. If phylloxerated vines and root-pruned vines are representative of chronically stressed and temporarily stressed vines, then these findings suggest that vineyard plots suffering both chronic and temporary stresses cannot be ranked for subsequent yields solely on their chlorophyll levels or its close correlate, remotely sensed canopy reflectance.

INTRODUCTION

For a vineyard that was uniform except for its phylloxera distribution we found high coefficients of determination, R^2, for linear regressions of grape yields vs. leaf and canopy spectral properties measured at ground level as well as remotely sensed by aircraft-mounted instruments. Ranks of plots within a vineyard by spectral differences anticipated by 5-17 months their ranks by yield. The ability to rank plots by anticipated yields assists growers in timing vineyard replacement; vines do not recover from phylloxera, a root-attacking insect, but follow a course of decline once they are infested. Our goal in this study was to compare the relationship of leaf spectral changes vs. yields for chronically stressed vines -- phylloxera-stressed in this case -- vs. the relationship between spectral properties and yields of temporarily stressed vines. If these spectral property-yield relationships differ between chronically stressed and temporarily stressed vines, one would need to supplement spectral data with ground level vineyard assessments to predict yield ranks of vineyard sections, if the vineyard contained both chronically and acutely (temporarily) stressed vines. Spectral changes that we found to vary with yield include transmission at 940 and 650 nm, which we measured in the field with a Minolta SPAD-502 chlorophyll meter. We also found the ratio of near infra-red:red reflectance (NIR:RED), which we measured remotely with aircraft-mounted sensors, also varied with yields. The field and remote sensing data were highly intercorrelated.

We choose root pruning as the temporary stress to contrast with phylloxera-induced stress which also causes root damage. In vineyards root pruning can be intentionally imposed to limit vine growth Huyssteen, 1991 #17 , or it may be the unavoidable consequence of tillage, or the installation of underground irrigation or drainage systems. In addition to mechanical pruning, roots may be "pruned" by fluctuating water tables and by soil dwelling animals.

MATERIALS AND METHODS

The Vineyard

The Cabernet Sauvignon/AXR#1 vineyard we studied was planted in 1981 on Clear Lake clay and Bale clay loam near Oakville California. The vineyard is nearly level, covers 12.2 acres, is drip irrigated, and has its 3.65m wide rows oriented NE to SW. Vines are 2.43m apart in rows. The vine trunks divide at 1.1m (the height of the first trellis wire) to form arms that extend in each direction down the vine row. A second wire 0.4m above the first supports fruiting canes.

Plot Selection

Figure 1 shows the location of the plots of vines studied. In 1993 we compared chlorophyll and yields of 18 phylloxera-undetected, untrenched vines in plots 7, 8, and 9 to those for 10 phylloxera-undetected, trenched vines in plots 10 and 11. By 1994 plots 8-11 where lightly infested with phylloxera; plot 7 was more heavily infested and not included in the 1994 comparisons. We trenched a new set of 10 vines per plot in plots 10 and 11 which we compared to 13 untrenched vines in plots 8 and 9. We added two additional trenched plots, 13 (10 vines) and 14 (9 vines), which were in an area severe phylloxera-induced decline. We compared these vines to 24 untrenched, vines with similar symptoms in plots 1, 2, and 3.

Root Pruning

On June 7, 1993, we dug on one side of the vines an 18" wide, 36" deep trench starting 10"-20" from the vine center. On May 5, 1994, we dug 42-48" deep, 18" wide trenches on both sides of the vines starting 6-12" from the row center.

Phylloxera Detection

We determined phylloxera presence by examining with a hand lens root pieces excavated by the trenchers or, for untrenched vines, excavated from a hole dug next to the trunks of vines that bordered the vines in the study. We assessed phylloxera of the bordering vines to avoid disturbing the roots of the studied vines. We assumed that phylloxera presence on the bordering vines indicated presence on the studied vines.

Fruit Yield

On September 27, 1993 and September 27, 1994 we recorded the cluster number and "first crop" fruit weight.

Field Chlorophyll Measurements

The Minolta SPAD-502 chlorophyll meter converts leaf transmission of 940 and 650 nm light to SPAD units, which had the following relationship to grape leaf chlorophyll concentration: Chlorophyll (mg/cm^2) = 0.001605*SPAD - 0.009951. $R^2 = 0.914$.

We averaged six SPAD readings per leaf. In 1993 measured leaves were two nodes above the second cluster on vigorous shoots.

All sampled shoots had clusters, generally two, but occasionally three. In the latter case, the sampled leaf opposed a cluster. After establishing that the coefficient of variation among selected shoots was less than 10%, we took one leaf from one vigorous shoot per vine and did not distinguish between shoots that grew from canes or spurs. We chose shoots on the southeast side. We took chlorophyll meter readings May 18, June 9, July 15, August 19, September 3 and 16, and October 20.

In 1994 we measured 4 leaves per vine, two from each side. (There were no differences between the southeast and the northwest sides.) We took leaves opposite the second cluster on May 5, and the second leaf above the second cluster on subsequent dates: May 25, June 29, July 26, and September 14.

Statistical Analysis

We did not detect any soil or irrigation gradients that might explain differences in chlorophyll and yield among plots that we have attributed to phylloxera or trenching. Nevertheless, we did not randomly assign "phylloxera and trenching treatments" to vines, so we did not have the benefit of randomization to minimize biases due to unrecognized field gradients in soil properties or other vineyard parameters. We used a repeated measurements design with univariate contrasts at each date to compare trenched vs. untrenched vines for chlorophyll content. We used a one-way ANOVA to compare yields. We analyzed data using SYSTAT software (SYSTAT 1992).

RESULTS

Chlorophyll measurements of uninfested vines in plots 10 and 11 taken just before 1993 root pruning were not significantly different from the comparison group of untrenched vines. Root pruning temporarily depressed chlorophyll with maximum depression occurring 47 days after root pruning. By 71 days after pruning chlorophyll of root-pruned vines was not significantly different from that of unpruned vines. See Figure 1. Root pruning reduced yields significantly.

In 1994 with lightly infested vines chlorophyll levels were significantly higher in plots 8 and 9 than in 10 and 11 on May 5, when vines in plots 10 and 11 were trenched. By May 25, the chlorophyll levels equalized between the two treatments; however, 55 and 82 days after trenching chlorophyll was significantly lower in the trenched vines. By mid-September, chlorophyll in the trenched vines had returned to being insignificantly different from that of untrenched vines. Root pruning reduced yields significantly. See Figure 2.

With heavily infested vines the root pruned vines began and finished the season with significantly more chlorophyll than the unpruned comparison vines; however, 82 days after root pruning chlorophyll in trenched vines dropped to the level of the untrenched vines. Yields did not significantly differ between root-pruned and unpruned vines. See Figures 3.

DISCUSSION AND CONCLUSION

Phylloxera reduces both chlorophyll and yields so that rankings of vines by chlorophyll content measured anytime during the growing season corresponds to subsequent rankings by yield. In contrast, trenching reduces yield but only depresses chlorophyll temporarily. Chlorophyll measurements of trenched vines taken before chlorophyll has declined and measurements taken after chlorophyll has recovered would not distinguish the vines from untrenched vines. Yet, the yields between the two groups of vines could be significantly different. (Only among the heavily infested plots, did trenching fail to reduce yields beyond that reduced by phylloxera.)

In a vineyard with plots differing in phylloxera infestation and root pruning one could not anticipate yield rankings of plots based solely on chlorophyll rankings or remotely sensed NIR:RED, which is highly correlated to chlorophyll. Even a cautious extrapolation of the results could have implications for remote sensing. Other chronic stresses (besides phylloxera) will likely lower chlorophyll and yields, and other temporary or relievable stresses (besides root pruning) will likely depress yields but allow chlorophyll recovery. Vineyards suffering from both chronic stresses and recoverable stresses will not be so exceptional that they can be ignored by interpreters of remotely sensed vineyard reflectance data. With such vineyards one would need additional information to anticipate how vineyard sections would rank by yields.

FIGURES

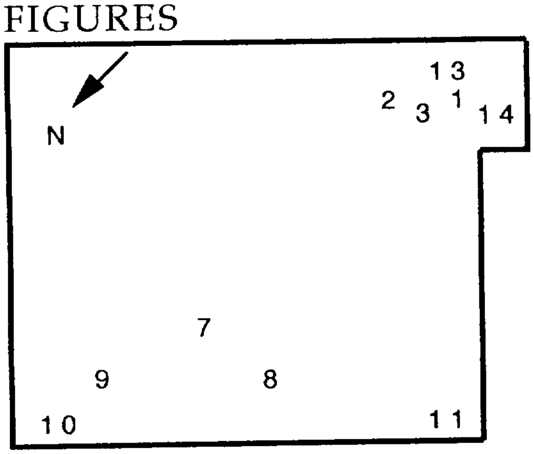

Figure 1

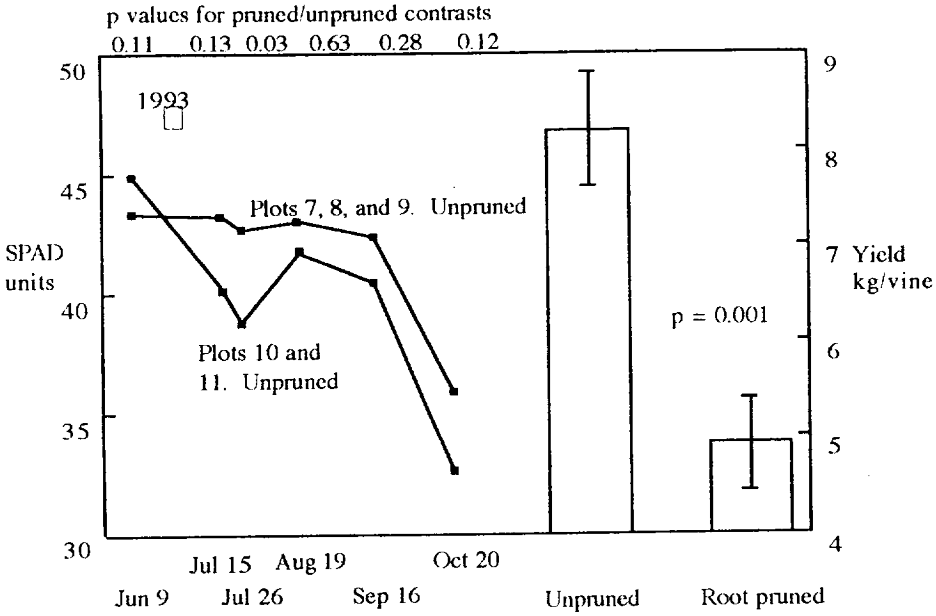

Figure 2

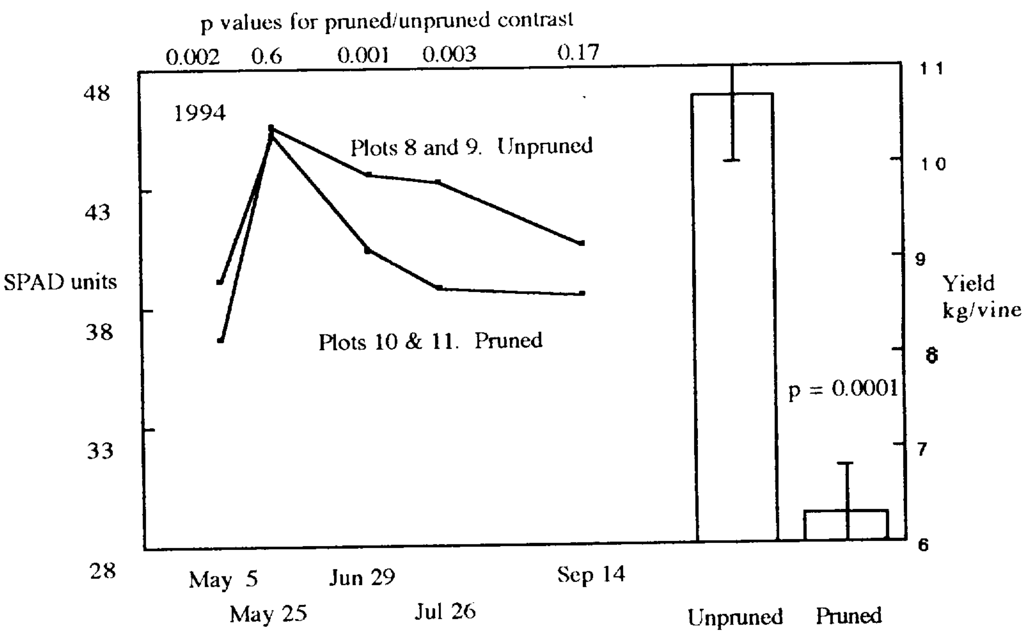

Figure 3

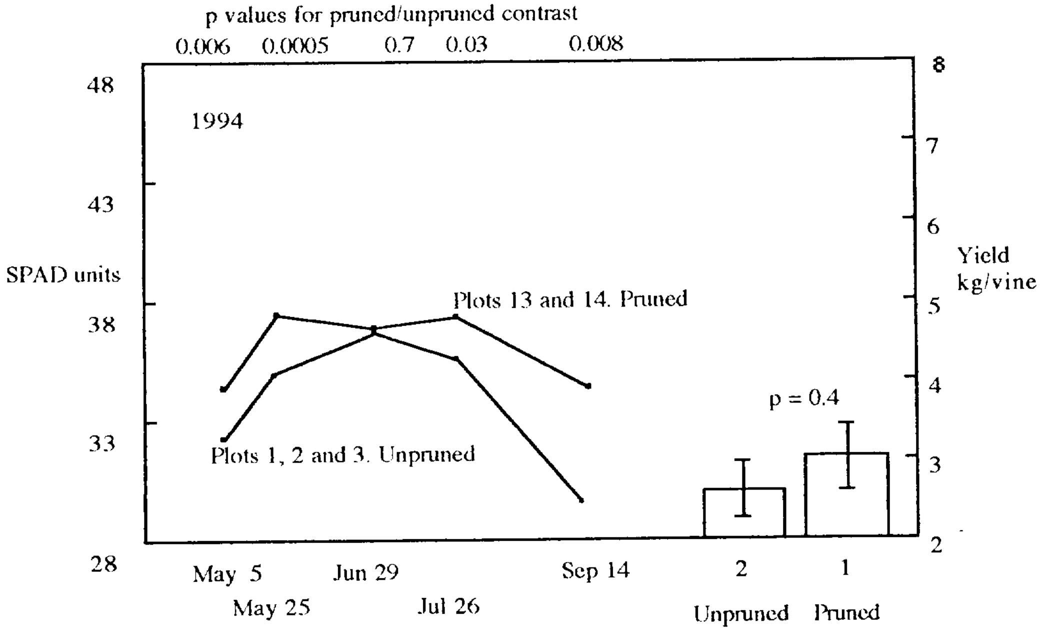

Figure 4.

FIGURE CAPTIONS

Figure 1 Map of study plots. Numbers designate plots.

Figure 2. Mean vine SPAD values for root-pruned and unpruned vines without detectable phylloxera. Probabilities are for root-pruned and unpruned contrasts at each sampling date in 1993. Mean vine yields for root-pruned and unpruned vines in 1993. Probability value for treatment difference is from anova.

Figure 3. Mean 1994 vine yields and SPAD values for root-pruned and unpruned vines lightly infested with phylloxera. Probabilities at each date are for root-pruned and unpruned contrasts of SPAD values Probability value for yield differences is from anova.

Figure 4. Mean 1994 vine yields and SPAD values for root-pruned and unpruned vines with severe phylloxera-induced symptoms. Probabilities at each date are for root-pruned and unpruned contrasts of SPAD values Probability value for yield differences is from anova.